Battlefield De-Confliction Sensor And Information System

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ABSTRACT

A battlefield de-confliction and assessment sensor system architecture is described that uses a hyper-spectral imaging spectrometer instrument onboard a robotic aerial vehicle (UAV) to identify, characterize, and track missiles and aircraft. An overview of the physical principles of imaging spectrometry for detailed characterization of remote objects and of gas vapors is given. The terms "multi-spectral,'""hyper-spectral," and "ultra-spectral" are defined within the framework of applications and instrument system design approaches. This is a passive sensor system and is neither a radar, nor a lidar. It applies developed hyper-spectral imaging technologies. New concepts include real-time hyper-spectral image processing and visualization and a new instrument.

Keywords: de-confliction, hyper-spectral, multi-spectral, sensor, spectrometry, ultra-spectral, wavelength.

1. INTRODUCTION

1.1 What is imaging spectrometry?

We human beings view our surroundings in color and draw conclusions about the character of the environment that affects our well-being. For example, red and yellow leaves on trees indicate the season is fall, and perhaps an overcoat is required. A 2-in. spherical object is observed to have a rough texture and be yellow—a clue this might be a lemon. We fuse our senses of color, shape, size, and weight to characterize our remote surroundings. The visual colors provide clues about the maturity and health of plants and help us to identify rock, soil, and mineral types. Our vision is limited to less than 10 percent of the spectral region available to imaging spectrometers. These new instruments that cover over 10 times the spectral region covered by the eye are powerful tools that are providing a new understanding of the world around us.

1.2 Fundamental principles

Each solid[1], liquid, and gas[2] has a unique spectral fingerprint characteristic of its chemical composition. These unique spectral fingerprints are seen using infrared spectrometers. Imaging infrared spectrometers are used to obtain information about the spatial distribution of solids, liquids, and gases. Solids are typically observed in reflected sunlight in the visible and in the near infrared wavelength regions. Imaging spectrometry from surfaces (liquids or solids) reveals information about the chemical composition of that surface. For example, soil types, minerals, and agriculture crops (oats, grasses, barley, etc.) are identified and characterized by interpreting data recorded by imaging spectrometers in aircraft or spacecraft. The molecular structure of gases *or* vapors are observed in either emission or absorption and typically in the 2- to 16 -μm wavelength region. Three categories of instrument systems are identified, based on a pre-defined measurement objective. These are multi-spectral, hyper-spectral, and ultra-spectral.

1.2.1 Multi-spectral

Instruments that record multi-spectral data are broadband spectral instruments that provide images in broad, select color bands not unlike the response of the eye to a color photograph. The colors that are used in the image are selected to maximize the contrast of those aspects of the object space irradiance distribution that are desired, Ten to twenty spectral bands spread between 0.4and14.0μm might be used, Most instruments, however, cover a much smaller wavelength Interval. For example, LANDSAT uses a few bands across visible and near-infrared wavelengths. This spectral resolution of $\Delta\lambda/\lambda \approx 0.1$, is used for terrain classification and land-use assessment.

1.2.2 Hyper-spectral

Instruments that record hyper-spectral data are the narrower-band spectral instruments that provide images in a large (100-200) number of select color bands. At this spectral resolution, the surface reflectance of solids and liquids reveal details of the chemical composition of solids The AVIRIS and the HYDICE instruments are examples of operational reflectance hyper-spectral imaging spectrometers. This spectral resolution of $\Delta\lambda/\lambda \approx 0.1$ is used for agriculture. forestry. mineral exploration, soils. watershed management, and analysis of the coastal zone. Information processing has been a limitation to the real-time applications of hyper-spectral instruments. However, new commercial off-the-shelf technology being used by the entertainment industry will quickly revolutionize the processing and data visualization from these instruments

1.2.3 Ultra-spectral

instruments that record ultra-spectral data are the narrowest-band spectral instruments that provide images in a large (1 000–10,000') number of select color bands. At this spectral resolution. the chemical composition of gases is revealed. The ATMOS. the AES. and the TES instruments are examples of ultra-spectral. This spectral resolution of $\Delta\lambda/\lambda \approx 0.1$ is used to determine the chemical composition of gases. information processing has been a limitation to the real-time applications of ultra-spectral instruments.

1.3 The hyper-spectral advantage

The hyper-spectral advantage is that by analyzing the entire ensemble of spectral lines from 2.5-to 5.0-μm wavelength across the field of view, sufficient information is provided about the spectral reflectance of the surface background, the atmospheric spectral absorption noise, and the plume spectral signature to determine the 3-D trajectory and to classify target type and operational scenario. Hyper-spectral instruments have been analysed for their value.[5]

1.4 What are we doing with it here?

A battlefield de-confliction and assessment sensor system architecture is described which uses a hyper-spectral imaging spectrometer instrument onboard a robotic aerial vehicle (UAV) to identify, characterize, and track missiles and aircraft. This is a passive sensor system and is neither a radar, nor a lidar. It applies developed hyper-spectral imaging technologies. New concepts include real-time hyper-spectral image processing and visualization and a new instrument.

2. PAYOFF TO THEATER DEFENSE

The payoff to theater defense is earlier detection and tracking of low-observable targets by enhanced background suppression and atmosphere removal, as well as real-time processing for real-time tracking. Vehicle identification is done using the vehicle's unique spectral fingerprint to classify target type and operational characteristics (altitude, range, fuel type). Also provided is the trajectory and state vector profile in three dimensions. This information will bean aid to battlefield de-conflict ion.

The system architecture is configured to provide real-time visualization of asset and threats distribution. A constellation of UAVS, each with the hyper-spectral system, will provide continuous discovery and passive re-interrogation and refinements of target information. The current architecture plans show that high-level data products (gee-located icons) are mapped on to a 3-D virtual representation of the battlefield in real time.

3. ONBOARD DATA PROCESSING STRATEGY

The onboard data processing strategy is divided into six parts: 1) Process the recorded emission spectra where H_20 and $C0_2$ emissions from the plume are bright and the spectral variation in the background is low, for example, in 250 spectral bands between 2,5 and 5.0 μm; 2) Analyze pixels across the scene by correlating between an emission spectrum recorded at a pixel with its nearest neighbor; make contours on the map where a pixel correlation with its nearest neighbor drops below a 2-σ threshold; 3) Correct for the atmosphere, and unmix the background spectrum by continuously retrieving/updating the model or the atmosphere and background before a target is detected; 4) Identify the vehicle type by a spectral-matched filter approach using an onboard reference library of plume source functions; 5) Perform single-vantage-point 3-D tracking by gauging the attenuating effects of the atmosphere on the plume signature; 6) Transmit to the ground an encrypted gee-located icon to position on a map.

Figure 1 shows a plot of radiance in units of (mW $cm^{-1} sr^{-1} \mu m^{-1}$) as a function of wavelength across the bandwidth 2.5 to 5.0 pm. We assume an observation angle of O deg; altitude of 50,000 ft; solar zenith angle of 30 deg; asphalt runway at temperature 315k; and a 2-m per side square pixel footprint.

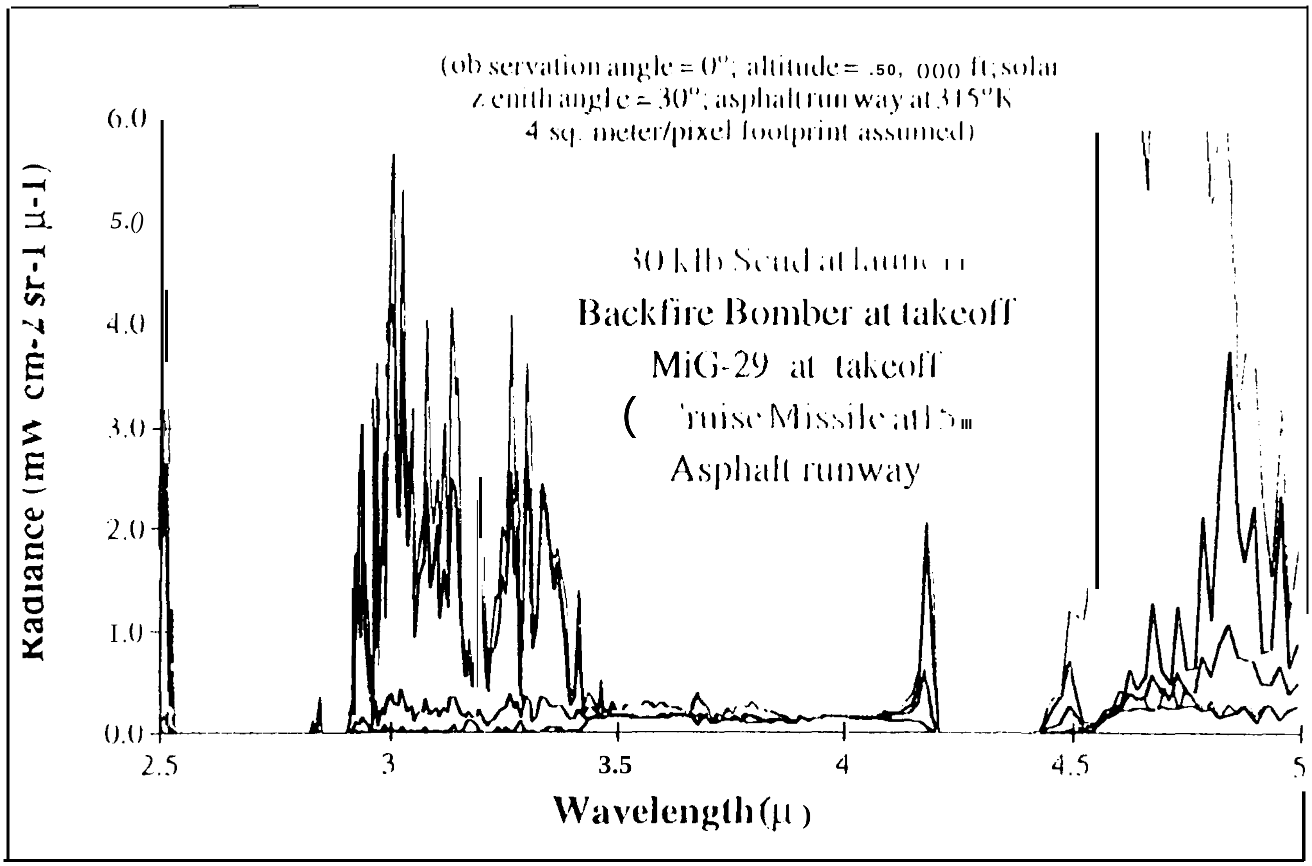

Fig. 1. Identification of weapons platforms: comparison of predicted plume signatures

Figure 2 shows the 3-dimensional tracking from a single vantage point to give altitude ranging. This is shown for a MIG 29 flying at 2.7 km over a vegetation canopy observed at zenith angle of 11 deg. Radiance is in units of ($mW\,cm^{-1}sr^{-1}\mu m^{-1}$) as a function of wavelength across the bandwidth 2.5 to 5.0 µm. The process is to take the observed spectrum, add noise, remove background, and cross-con-elate the observed spectra with the reference spectra. The reference spectra are shown as the set of spectra modeled for each km from O to 6 km. The reference spectra are shown in units of ($mW\,cm^{-1}\,sr^{-1}\mu m^{-1}$) as a function of wavelength across the bandwidth of 2.5 to 5.0 pm. Analysis of the behavior of the correlation coefficient as a function of the altitude of the MIG 29 reference spectrum altitude indicates that altitude can be determined to within ±0.5 km.

4. SUMMARY

We have suggested an onboard data processing strategy for a special-purpose imaging spectrometer to enable the detection, identification, tracking, and ranging of scud and other missiles from a high-flying UAV platform and provide that information on maps to a field commander. Detecting targets and distinguishing them from the backgound is done by cross-correlating spectrally resolved, spatially mapped pixels with each of their nearest neighbor pixels. Identification of exhaust plumes is done by calculating a merit function (for example, correlation coefficient divided by residual error) that optimally matches both the emission pattern and the relative brightness of the plume to template archived within an onboard signature library. Tracking and ranging in three dimensions with a single, non-stereoscopic view of the target is performed by gauging the optical depth of the atmosphere separating the instrument and the target.

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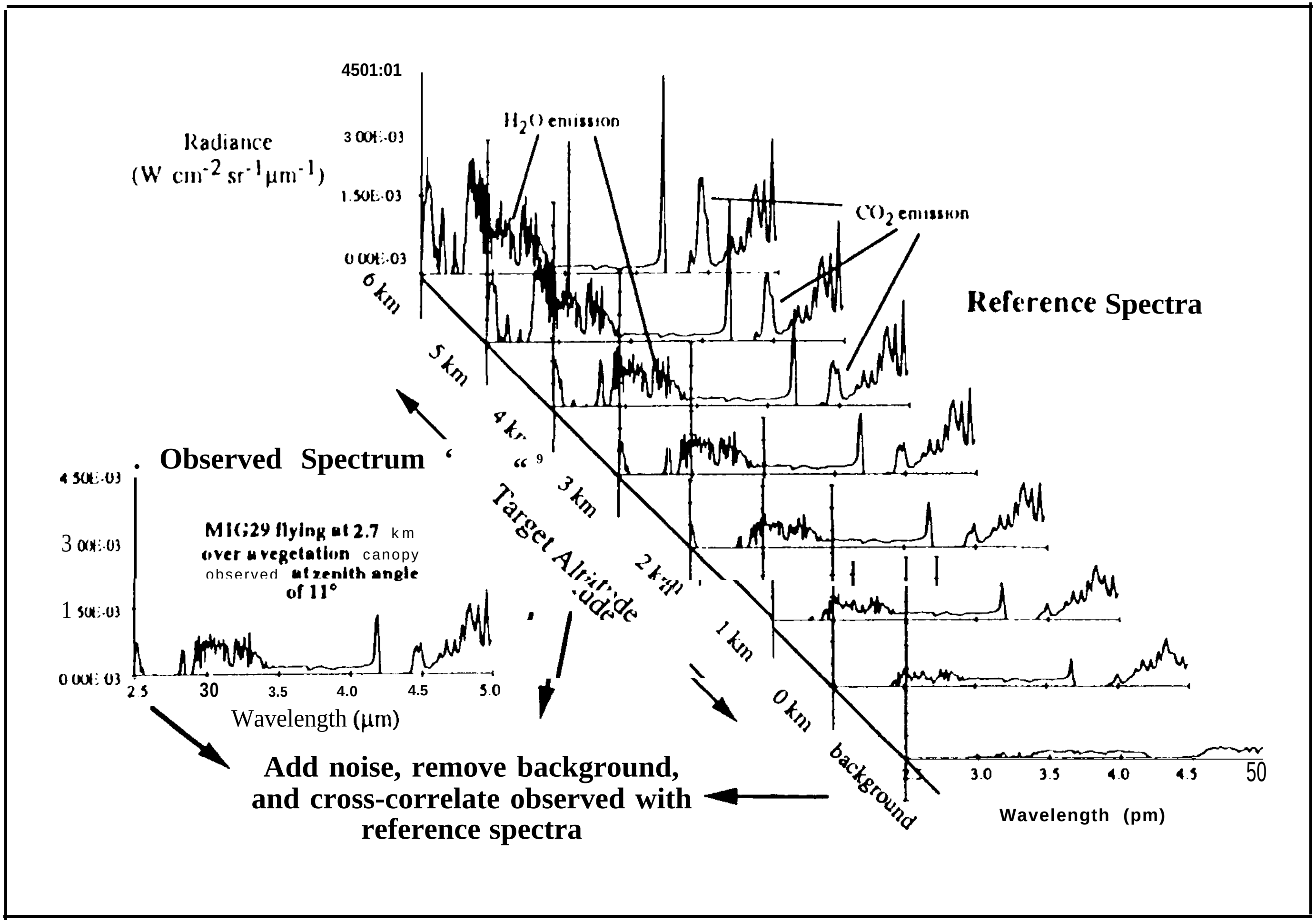

Fig. 2. 3-D tracking from a single vantage point: altitude ranging

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